

## INTEGRATED PHOTOVOLTAIC ROOFING SYSTEM

## 5 FIELD OF THE INVENTION

The present invention relates to roofing components, panels and systems, and more particularly, to a photovoltaic roofing component, panel and system having solar or photovoltaic modules integrated with a flexible membrane to protect a building from environmental elements while also generating electricity.

## DESCRIPTION OF RELATED ART

Various types of roofing materials have been utilized to provide building structures protection from the sun, rain, snow and other weather and environment elements. Examples of known roofing materials include clay tiles, cedar and composition shingles and metal panels, and BUR materials, (e.g., both hot and cold applied bituminous based adhesives, emulsions and felts), which can be applied to roofing substrates such as wood, concrete and steel. Additionally, single-ply membrane materials, e.g., modified bitumen sheets, thermoplastics such as polyvinylchloride (PVC) or ethylene interpolymer, vulcanized elastomers, e.g., ethyl propylene diene (monomer) terpolymer (EPDM) and Neoprene, and non-vulcanized elastomers, such as chlorinated polyethylene, have also been utilized as roofing materials.

While such roofing materials may be satisfactory for the basic purpose of protecting a building structure from environmental elements, their use is essentially limited to these protective functions.

Solar energy has received increasing attention as an alternative renewable, non-polluting energy source to produce electricity as a substitute to other non-renewable energy

resources, such as coal and oil that also generate pollution. Some building structures have been outfitted with solar panels on their flat or pitched rooftops to obtain electricity generated from the sun. These "add-on" solar panels can be installed on any type of roofing system as "stand alone" solar systems. However, such systems typically require separate support structures that are bolted together to form an array of larger solar panels. Further, the "add-on" solar panels are heavy and are more costly to manufacture, install and maintain. For example, the assembly of the arrays is typically done on-site or in the field rather than in a factory. Mounting arrays onto the roof may also require structural upgrades to the building. Additionally, multiple penetrations of the roof membrane can compromise the water-tight homogeneity of the roof system, thereby requiring additional maintenance and cost. These "add-on" solar panel systems may also be considered unsightly or an eyesore since they are attached to and extend from a roof. These shortcomings provide a barrier to more building structures being outfitted with solar energy systems which, in turn, increase the dependence upon traditional and more limited and polluting energy resources.

Other known systems have combined roofing materials and photovoltaic solar cells to form a "combination" roofing material which is applied to the roof of the building structure. For example, one known system includes a combination of a reinforced single-ply membrane and a pattern of photovoltaic solar cells. The solar cells are laminated to the membrane and encapsulated in a potting material. A cover layer is applied to the combination for protection. The solar cells are interconnected by conductors, i.e., conductors connect each row in series, with the inner rows being

connected to the outer rows by bus bars at one end, and with the other ends terminating in parallel connection bars.

5            However, known combinations of roofing materials having solar cells can be improved. For example, known combinations of solar cells and roofing typically require multiple internal and external electrical interconnections to be performed on site in order to properly connect all of the solar modules.

10          As a result, substantial wiring, connectors and related hardware are needed to properly wire all of the individual solar cells. Such wiring is typically performed by an electrician rather than a roofer, thereby increasing labor costs and complicating the installation. Additional wire and

15          connection components can also result in composite roofing panels requiring excessive field handling and weight, thereby making storage, transportation, and installation of panels more difficult and expensive. Further, a multitude of interconnections must typically be completed before an

20          installer can run multiple wires or connection lines to an electrical device, a combiner box or an inverter. Finally, increasing the number of wires and interconnections in a panel to be installed under field conditions increases the likelihood that the electrical connection in the panel will be

25          broken, e.g., by variables associated with constructive field conditions or wire connections being exposed to inclement weather and/or other hazards (rodents, pigeons, etc.)

            A need, therefore, exists for an integrated photovoltaic roofing component and panel that reduces the need for separate

30          installers to handle roofing materials and solar and related electrical components. The component and panel should also be conveniently stored and transported, and utilize a more efficient wiring system to simplify the installation of

photovoltaic roofing components and panels, thereby reducing the maintenance and operational costs of the system.

5       SUMMARY

10       The present invention relates to an integrated solar or photovoltaic roofing component, panel and system that can be attached to a roofing surface. The component, panel and system includes a flexible membrane sheet and a plurality of elongated solar or photovoltaic modules. The plurality of elongated photovoltaic modules is attached to a top surface of the flexible membrane sheet. Each module is arranged side-by-side or end to end such that the electrical leads are located at adjacent ends of the modules. Thus, the wiring ends can be aligned with or adjacent to each other to form the integrated photovoltaic roofing component, panel or system.

15       In some embodiments of an integrated photovoltaic roofing component and panel constructed in accordance with the invention, electrical interconnections between individual solar cells of a solar module are completed before the plurality of solar modules are adhered to the flexible membrane. As a result, the installer is not required to connect positive and negative electrodes of each individual solar cell, thereby reducing the electrical interconnections between all the solar cells and modules. Thus, the integrated photovoltaic roofing panel can be unrolled onto a roof of a building structure and installed and properly connected with fewer electrical components and connections than conventional combination photovoltaic systems.

20       In some embodiments, because the cells are preassembled into modules, the edges of the elongated solar modules may be encapsulated with a sealant.

In some embodiments, a "panel" includes about two to  
twelve elongated photovoltaic modules. A panel can include  
5      two modules with wiring ends facing each other, or pairs of  
modules can be arranged in two sub-panels of about one to six  
modules. The sub-panels are arranged such that the wiring  
ends of the modules are in close proximity to each other on  
the flexible membrane. Electrodes are mounted in the wiring  
10     ends, thereby providing a central location having all of the  
electrodes to be accessed. Each solar module includes a  
positive electrode and a negative electrode.

          In some embodiments, the electrodes can be accessed  
through apertures defined by apertures cut into in the  
15     flexible membrane. Solder sections are inserted through the  
apertures and connected to the module electrodes. The set of  
electrodes of the modules may then be connected in a  
combination of series and parallel connections to complete the  
wiring of the panel. The wiring series combines into a plug  
20     or other connector. The wires, electrodes and solder sections  
are hermetically sealed within the flexible membrane  
(utilizing adhesive, hot-air welding or radio frequency  
welding), and the plug is handily available for connection to  
another photovoltaic roof panel to form a larger array or  
25     system or to an inverter or current converter.

          Some embodiments of an integrated photovoltaic roofing  
system constructed in accordance with the invention include  
solar modules that are connected together via electrical  
connections made in a conduit that runs adjacent to the solar  
30     modules. In these embodiments, wires are attached to the  
electrodes of each of the photovoltaic modules. When the  
panel is assembled on a roof, the wires from the photovoltaic  
modules may be made connected together within the conduit.  
Thus, the conduit may provide strain relief for the

connections and may protect the connections protected from the environment.

In some embodiments, a "quick-connect" is attached to each of the wires from the photovoltaic modules and to the wiring in the conduit. The use of "quick-connects" enables an installer to make the connections relatively quickly and easily.

# BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIGS. 1A-D illustrate various integrated roofing component configurations having two modules and six modules;

FIG. 2A illustrates an integrated roofing panel having two groups of six modules arranged side-by-side , and Figure 2B illustrates an alternative panel configuration with two groups of three modules;

FIGS. 3A-B illustrate the manner in which an integrated photovoltaic roofing component or panel can be applied to a flat and pitched rooftop of a building structure;

FIG. 4 is a cross-section view of an integrated photovoltaic roofing component or panel according to the present invention;

FIG. 5 is a cross-section view of an exemplary photovoltaic module;

FIG. 6 is a cross-section view of the exemplary photovoltaic module of Fig. 5 that is laminated or adhered to a flexible membrane to form an integrated roofing component or panel;

FIGS. 7A-C are respective top, bottom and exploded views of module electrodes;

FIG. 8 is an exploded view of an edge of a module showing the electrodes in further detail and apertures formed through a flexible membrane;

FIG. 9 is a top view of an integrated photovoltaic roofing panel having two groups of six modules arranged side by side and facing each other with electrodes connected in series;

FIG. 10 is a cross-section view of the electrodes located beneath the membrane and insulation layers of a photovoltaic integrated component or panel;

FIG. 11 illustrates a system including an integrated photovoltaic roofing panel according to the present invention and an inverter for generating alternating current electricity;

FIG. 12 is a flow diagram of one embodiment of a process of manufacturing an integrated photovoltaic roofing component or panel according to the present invention;

FIG. 13 illustrates one embodiment of an integrated photovoltaic roofing system constructed according to the invention;

FIG. 14 illustrates a partial top view of the embodiment of FIG. 13 illustrating connections that may be made in the embodiment of FIG. 13;

FIG. 15 illustrates one embodiment of a conduit constructed according to the invention;

FIG. 16 is a cross-section view of a photovoltaic module that is laminated or adhered to a flexible membrane to form an integrated component according to the present invention;

FIG. 17 illustrates a partial side perspective view of the embodiment of FIG. 13 illustrating connections that may be made in the embodiment of FIG. 13; and

FIGS. 18A and 18B depict flow diagrams of one embodiment of a process of manufacturing and installing an integrated photovoltaic roofing system according to the present invention.

#### DETAILED DESCRIPTION

The present invention relates to an integrated roofing component, panel and system. The component, panel and system include a plurality of solar or photovoltaic modules ("PV modules") attached to a flexible membrane sheet, such as a single-ply membrane. The modules are arranged adjacent each other, e.g., side-by-side or end-to-end. The ends of the modules have electrical connectors or electrodes that are arranged to face each other or are adjacent or aligned with each other.

In some embodiments, the electrical connectors extend from internal module electrodes of the solar modules and can extend through apertures formed in a bottom surface of the flexible membrane.

In some embodiments, photovoltaic modules are connected together by routing electrical connectors from each photovoltaic module into a conduit and connecting the electrical connectors in the conduit.

The electrical connectors conduct direct current (DC) electricity that may be connected directly to DC electrical devices or connected to an inverter that provides alternating current (AC) electricity to residential, commercial or industrial building structures. Additionally, the AC electricity can also be reverse metered into a utility grid.

The ends and sides of the elongated edges of the PV module of a roofing component or panel can be sealed for protection.



Protective outer layers can also be applied over the electrical connectors and on the flexible membrane to hermetically seal the apertures that are used to access the internal module electrodes along with the copper wiring utilized to string the individual modules in a series leaving a "quick-connect" plug readily available to connect with the next PV roofing component or panel.

10      In a panel constructed according to these embodiments, the wiring of modules is simplified, and the amount of time required to install photovoltaic roofing panels is reduced since many of the wiring connections may be made prior to field installation and, in some embodiment, encapsulated within a central area. Accordingly, the number of field connections required to connect individual components or panels may be substantially reduced.

Having generally described some of the features of the present invention, in the following description, reference is made to the accompanying drawings which form a part hereof and which show by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized as structural changes may be made without departing from the scope of the present invention.

25      Referring to Figures 1A-C, one embodiment of the present invention provides an integrated photovoltaic roofing component 100. One exemplary integrated photovoltaic roofing component 100 includes a plurality of elongated photovoltaic or solar modules 110 and 111 (generally module 110). Each module 110 is a collection of solar cells, e.g., cells 110a-v and 111a-v (generally solar cell 110a). A solar cell 110a is the smallest photoactive unit of a solar module 110. The exemplary modules 110 shown in Figures 1A-C include twenty-two

(22) photovoltaic cells 110a, but other numbers of solar cells 110a can be utilized.

Each solar module 110 has a first elongated side 130, a second elongated side 132, a front or head or electrode end 134, a rear or butt end 136, a top surface 138, and a bottom surface 139 (not visible in top view of Figure 1). The bottom surfaces 139 of the modules 110 are bonded, adhered or laminated to a top surface 142 of a flexible membrane 140. A bottom surface 144 (not visible in top view) of the flexible membrane 140, or another layer that is attached to the bottom surface 144, is attached, either partially or fully, to a roofing surface of the building structure such as a roof, wall, canopy, or another building structure.

The modules 110 are arranged such that one end of the modules 110, i.e., the ends having electrical connectors, e.g., soldering pads or wire or copper tape leads 170 and 171 (generally connectors 170) are adjacent each other. Each connector 170 includes a negative lead 170a and a positive lead 170b that are connected with adjacent module electrodes. The electrical connections can be in series or in parallel. However, for purposes of explanation and illustration, this specification refers to series connections. For example, in Figure 1A, the elongated sides 130 and 132 of modules 110 and 111 are side by side and adjacent each other. In Figure 1B, the modules 110 and 111 are adjacent each other and staggered or offset such that the electrode ends 134 are near or adjacent each other. In Figure 1C, the electrode ends 134 are adjacent and face each other. As shown in Figures 1A-C, the electrode ends 134 with the electrical connectors or wire ends 170 are contained within a common or central area 160.

With these exemplary configurations, the time required to connect each photovoltaic module 110 is reduced since the

module electrodes 170 can be connected by, for example, soldering, within the central area 160. Thus, the present invention reduces the amount of work performed by electricians.

Persons of ordinary skill in the art will recognize that the exemplary roofing components 100 shown in Figures 1A-C can include different numbers of modules 110 having different numbers of solar cells 110a and can be arranged in various configurations, and that the exemplary component 100 configurations shown are merely illustrative of these other configurations. For example, as shown in Figure 1D, an exemplary roofing component 100 includes six modules 110-115 arranged side-by-side such that the wire connectors 170 - 174 are located at the same end 134 and are adjacent each other in the central area 160.

Referring to Figure 2A, the components 100 shown in Figures 1A-D can be used to form an integrated photovoltaic panel 200. An exemplary panel 200 includes two groups of modules 210 and 212 (generally "group 210"), each group having six modules. Specifically, modules 110-115 are arranged side-by-side in the first group 210, and modules 116-121 are arranged side-by-side in the second group 212. In this exemplary panel 200, the modules 110 of each group are arranged so that the electrode or leading ends 134 are adjacent and face each other. For example, the electrode ends 134 of modules 110 and 121 face each other, and the electrode ends 134 of modules 111 and 120 face each other. As a result, the electrode ends 134 with the electrical connectors 170-181 (generally 170) are aligned and the positive and negative leads 170b and 171a of modules 110 and 111 respectively can be connected in series within the central area 160. Inter-module connections (in this "daisy-chain" example: 170b-171a, 171b-

172a, . . . 180b-181a) within the central area 160 are completed in a manufacturing facility prior to field installation thus reducing time and complexity required during on site.

For purposes of explanation and illustration, Figure 2A shows an integrated photovoltaic roofing panel 200 having twelve modules 110 in two groups 210 and 212, each group having six modules 110. However, many panel 200, module 110, cell 110a and group configurations can be utilized. An integrated photovoltaic roofing panel 200 can include different numbers of modules 110 depending on the dimensions of a roofing surface to be covered. For example, as shown in Figure 2B, a panel 200 includes two groups 210 and 212, in which the modules are adjacent each other and arranged in a staggered configuration. Each group has three modules 110 - 112 and 113 - 115 with electrode pairs 170 - 172 and 173 - 175, respectively. Further, a panel 200 can include modules 110 having different numbers of solar cells 110a (Figure 1 illustrates twenty-two solar cells 110a in an exemplary module 110). Thus, the present invention is flexible and adaptable to satisfy the needs and dimensions of a building structure or size of an underlying flexible membrane 140.

Figures 3A-B show an integrated roofing panel 200 applied to a rooftop of a building structure for purposes of protection from the environment, as well as producing electricity. Specifically, Figure 3A illustrates an integrated photovoltaic panel 200 with modules 110-121 attached to a flexible membrane sheet 140. The membrane sheet 140 is applied to the roofing surface 300 of a building structure 310. The exemplary panel 200 covers a portion of the flat roof surface 300, but the remainder of the roof 300 can be similarly covered by other panels 200 or smaller

components 100 as needed. Similarly, Figure 3B illustrates a panel 200 with modules 110-121 attached to a flexible membrane sheet 140 that is applied to a pitched or angled roof surface 320 of a building structure 330. The remainder of the roof 320 can also be similarly covered.

Persons of ordinary skill in the art will recognize that more than one panel 200 or component 100 can be installed on a rooftop or other building surface or structure depending on the size of the surface and desired solar capabilities. Further, the panels 200 can have different numbers and sizes of solar modules 110 and flexible membrane sheets 140. For purposes of illustration, this specification generally refers to modules attached to a single membrane sheet, but various sizes and numbers of flexible membrane sheets can be used. Thus, the integrated photovoltaic panel 200 and component 100 of the present invention are efficient, effective and flexible photovoltaic roofing materials with simplified wiring.

Figures 4-12 illustrate various aspects of an integrated photovoltaic component 100 and panel 200, electrical connections, a system incorporating a component 100 or panel 200, and a method of manufacturing a component or panel. While the following description generally refers to a photovoltaic roofing "panel", persons of ordinary skill in the art will recognize that the description also applies to an integrated photovoltaic roofing component 100 or a combination of one or more components and panels.

Figure 4 shows a general cross-section of an integrated photovoltaic roofing panel 200 of the present invention. An exemplary solar module 110 or 111 (generally 110) that is adhered to the flexible membrane 140 can be solar module model no. PVL-128 or a UNI-SOLAR® PVL solar module, available from Bekaert ECD Solar Systems, LLC, 3800 Lapeer Road, Auburn

Hills, Michigan. This specific exemplary solar module 110 is adhered to the top surface 142 of the flexible membrane 140 with an adhesive 400. One exemplary adhesive 400 that can be used to bond or laminate the bottom surface 139 of the module 110 to the top surface 142 of the flexible membrane 140 is a reactive polyurethane hot-melt QR4663, available from Henkel KGaA, Kenkelstrasse 67, 40191 Duesseldorf, Germany.

One exemplary flexible membrane sheet 140 that can be used is a single-ply membrane, e.g., an EnergySmart® S327 Roof Membrane, available from Sarnafil, Inc., Roofing and Waterproofing Systems, 100 Dan Road, Canton, Massachusetts. Persons of ordinary skill in the art will recognize that while one exemplary flexible membrane 140 is selected for purposes of explanation and illustration, many other flexible membranes and single-ply membranes can be utilized. For example, alternative single-ply membranes 140 that can be used include modified bitumens which are composite sheets consisting of bitumen, modifiers (APP, SBS) and/or reinforcement such as plastic film, polyester mats, fiberglass, felt or fabrics, vulcanized elastomers or thermosets such as ethyl propylene diene (monomer) terpolymer (EPDM) and non-vulcanized elastomers such as chlorinated polyethylene, chlorosulfonated polyethylene, polyisobutylene, acrylonitrile butadiene polymer.

The module 110 includes negative and positive internal electrode soldering pads 170a(-) and 170b(+), respectively. Insulating tape 492 is applied to soldering pad 170a. Apertures 450a and 450b are formed through the flexible membrane 140, adhesive 400 and a lower portion of the module 110, to access the internal module soldering pads 170a and 170b. Solder connections or sections 470a and 470b are formed within the apertures 450a and 450b. The module 111 includes a

similar arrangement of negative and positive electrode soldering pads 171a(-) and 171b(+), apertures 451a and 451b, and solder sections 471a and 471b. Insulating tape 493 is applied to soldering pad 171a.

The solder sections 470a and 470b provide an electrical connection between the internal module soldering pads 170a and 170b and respective inter-module wire connection leads 430 and 431. As a result, the internal module negative electrode 170a, solder section 470a, and connection electrode 430 provide an electrical circuit with the terminus of wire 430 ending in a quick-connect plug (not shown in Figure 4). The internal positive module electrode 170b, solder section 470b, and inter-module connection lead 431 provide an electrical circuit connecting in series to the adjacent internal negative module electrode 171a through solder section 471a. In this series wiring example, the pattern of wiring positive to negative between adjacent modules is continued until all additional module electrodes are "daisy-chained" to complete the series circuit. The final positive internal module connection to electrode 181b (+) (see Fig. 2) terminates the series wiring with connection to a quick-connect plug (not shown in Figure 4) similar to termination to wire 430.

If necessary, one or more insulative layers 490 can be applied to the bottom surface 144 of the flexible membrane 140 and over the connection electrodes 430 and 431 and additional module electrodes in the electrical path for protection and support. The insulative layer 490 can be applied by an adhesive layer 480.

An edge sealant 495 can be applied to the edges of modules 110 and 111. More specifically, an edge sealant 495 can be applied to seal or cover any gaps or an edge between an adhesive layer 400 and the bottom surfaces of modules 110 and

111, as well as an edge between the adhesive layer 400 and the top surface 142 of the membrane 140.

Panels 200 having the general configuration shown in Figure 4 can be rolled up for storage and transportation. For example, typical rolls of a flexible membrane 140 can have a width as large as about 10 feet and a length cut and rolled to between about 30 or 100 feet. Modules 110 can be applied to the flexible membrane 140 and cut to various dimensions as needed, and are then unrolled and applied to a rooftop.

Figure 5 shows a cross-section of a solar module 110 that is generally representative of the exemplary solar module 110 model no. PVL-128 or a UNI-SOLAR® PVL solar module, available from Bekaert ECD Solar Systems, LLC, 3800 Lapeer Road, Auburn Hills, Michigan. This particular solar module 110 includes twenty-two solar cells 110a (as illustrated in Figures 1 and 2A-B).

This particular exemplary solar module 110 includes a top Tefzel layer 500 having a thickness of about two (2) mil (1 mil = 0.001 inch), a first ethylene-propylene rubber (EVA) layer 510 having a thickness of about 26 mil beneath the Tefzel layer 500, a fiberglass layer 520 having a thickness of about 15-20 mil beneath the EVA layer 510, a photoreactive or solar cell layer 530 having a thickness of about 5 mil beneath the fiberglass layer 520, a second EVA layer 540 having a thickness of about 8 mil beneath the photoreactive layer 530, and a Tedlar layer 550 having a thickness of about 2-5 mil beneath the second EVA layer 540. Figure 5 also shows the negative internal electrode 170a and the positive internal electrode 170b mounted within the second EVA layer 540 of the module 110. The negative internal electrode 170a is insulated from the photoreactive layer 530 by an insulation strip or layer 492 to prevent a short circuit.



The exemplary solar module 110 model no. PVL-128, as manufactured, typically includes a factory bonding adhesive 560 (shown as dotted line) on the underside of the module laminate, *i.e.*, applied to the underside of the Tedlar layer 550. However, for purposes of attaching or laminating the solar module 110 to the top surface 142 of the flexible membrane 140 in the present invention, this factory adhesive 560 can be replaced by the hot melt adhesive 300 mentioned earlier or an adhesive applied using another adhesion process.

Figure 6 illustrates a cross-section of an integrated photovoltaic roofing panel 200 in which the module 110 (with components illustrated in Figure 5) is laminated or adhered to the top surface 142 of the flexible membrane 140. Specifically, apertures 450a and 450b are formed through the membrane sheet 140, adhesive 400, and the bottom surface or underside of the module, *i.e.*, through the Tedlar layer 550 and partially through the second EVA layer 540 to access the internal electrodes 170a and 170b within the second EVA layer 540. Figure 6 also shows edge seals 495 applied over the membrane layer 140, and to the adhesive 400, and module 110.

After the solder sections 470a and 470b are applied to the internal module electrodes 170a and 170b through the apertures 450a and 450b, and the connection electrodes 430 and 431 are connected to respective solder sections 470a and 470b, a second adhesive layer 480 can be applied to the bottom surface 144 of the membrane 140. Additionally, an insulative membrane layer 490 can be applied to the bottom of the adhesive 480 (or to the bottom surface 144 of the membrane 140 if the adhesive 480 is not utilized). The insulative layer 490 insulates and encapsulates the connection electrodes 430 and 431 and additional module electrodes in the electrical

path. An exemplary membrane layer 490 that can be used is 48 mil S327, available from Sarnafil 100 Dan Road, Canton, MA.

The bottom surface of the panel 200, is applied to the roofing surface or substrate (e.g., roof sections 300, 320 in Figure 3) or other building structure surfaces. Thus, when the panels 200 are to be installed, the panel roll can be unrolled onto the rooftop and attached thereto using various known techniques (e.g., various adhesives utilized to adhere the flexible PV panel to the substrate or mechanical attachment utilizing screws and plates, combined with hot air welding, solvent welding or radio frequency (RF) welding of the laps or seams. Also, double-sided adhesive tapes, pre-applied adhesive with removable release paper, techniques may be utilized.)

As illustrated in Figures 7A-B, electrode leads 170a and 170b are connected to the connection electrodes 430 and 431, and located near the edge of the module, e.g., the electrode or reference edge 134. Figure 7C shows the ends of the leads 170a and 170b having termination holes 700 and 702 for series connection to wires or other connectors.

The wire or copper tape leads 170a and 170b are illustrated in further detail in Figure 8. Specifically, the leads 170a and 170b are connected respectively to the connection electrodes 430 and 431. The leads 170a and 170b extend perpendicular relative to the reference edge 134 of the module 110 and over the membrane 140. In the example for series wiring shown in Figure 2A, the inter-module connection electrodes are connected in this pattern with the exception of the inter-module connection between the positive internal module electrode 175b of module 115 and the negative internal module electrode 176a of module 116. In this case, the single electrical lead making the electrical circuit between 175b and

176a (See Figure 2A) extends across the reference edges 134 of modules 115 and 116. Thereafter, a wiring pattern similar to modules 110 through 115 is completed for modules 116 through 121.

As illustrated in Figure 9, the wire or internal module copper tape leads 170a and 170b are connected in series with connectors 430 and 431 of module 110. Specifically, the positive leads 170b - 174b and negative leads 171a-175a of modules 110-115 of the first group 210 are connected in series by connectors 431-435, and the positive leads 176b-180b and the negative leads 177a-181a of modules 117-121 are connected in series by connectors 437-441 in the second group 212. The negative lead 175b and the positive lead 175b of modules 115 and 116 are also connected by cross connector 436, thus completing the series connection of the modules 110-121. Negative and positive "quick-connect" plugs 920 and 922 terminate the ends of leads 430 and 442 external to the encapsulation membrane 490 and are readily available to connect to the adjacent PV panel. Further, one or more of these series connected panels can be connected in parallel to an inverter. Other electrical connections can also be used depending on the needs of a particular system, e.g., panels can be connected in parallel.

For example, a panel 200 having twelve modules 110 wired with the previously described series arrangement can provide 1536 Wstc and 571.2 Voc output. This configuration also contains the wiring for the solar modules 110 within the middle section 160, thereby simplifying the installation procedure. The output connections 430a and 442 can then be directed to a device which can process the solar energy and provide electricity to the building structure or reverse metered into a power grid. Further, a protective coating or

layer 490 can be applied over the wire leads 170a-181a and 170b-181b for protection from inclement weather, animals, and other environment factors.

Figure 10 shows an illustrative example of a cross-section of an integrated photovoltaic component 100 or panel 200 that is attached to a roof or decking. In this example, an insulation layer 610 is laid onto a decking 1000 with, for example, an underlying insulation substrate 1010. A groove 1020 is cut within the insulation layer 610. An electrical conduit 1030 within the groove 1020 contains the cables 430 and 442 (see also Figure 9) connected by cable quick-connects 920 and 922 to home-run cable quick-connects 1050 and 1052 and extending therefrom as DC cables to either electrical combiner box and/or inverter.

Figure 11 generally illustrates a system 1100 for providing electricity generated by integrated photovoltaic roofing panels 200 of the present invention to a building structure. Generally, the panels 200a and 200b are manufactured and wired as previously described and illustrated. The series leads or electrodes from the modules are connected in parallel to an interface or current converter, such as an inverter 1110, for converting the Direct Current (DC) electricity 1120 generated by the solar panels 200a and 200b into Alternating Current (AC) electricity 1130 at a certain voltage that can be utilized by the building structure or reverse metered into a power grid. One exemplary inverter 1110 that can be used is a photovoltaic static inverter, model no. BWT10240, Gridtec 10, available from Trace Technologies, Corp., Livermore California. These exemplary inverters 1110 are rated up to 600 volts DC input; 10kW, 120/240 or less, with single-phase output. Other inverters that can be utilized include a string inverter or the Sunny

Boy@2500 string inverter, available from SMA America, Inc., 20830 Red Dog Road, Grass Valley, CA. A further exemplary inverter 1100 that can be used is the Sine Wave Inverter, model no. RS400, available from Xantrex Technology, Inc., 5916 195th Street, Arlington, Washington or a 20kW Grid-Tied photovoltaic inverter, model no. PV-20208, also available from Xantrex.

Having described the integrated photovoltaic roofing component 100, panel 200, and system 1100, this specification now generally describes the process for manufacturing a component 100 or panel 200 and the processing of the modules, membrane, adhesives and electrodes, and wire leads. Generally, the process involves positioning modules to be laminated, laminating the modules and flexible membrane together, sealing the edges of the laminated panel as necessary, and wiring the panel.

Referring to Figure 12, initially, the module surfaces are prepared or activated in step 1200. Specifically, the bottom or Tedlar surfaces of the modules are activated by using, for example, a flame/corona treatment system. A combination of flame and electrical discharge corona treatment activate module surfaces which will receive a first hot-melt adhesive used to laminate the bottom surfaces of the modules to the top surface of the flexible membrane sheet. The substrate of the module can be cleaned and roughened to prepare for application of adhesive. For example, the module can travel across a flame (e.g., a 175 mm wide burner head (FTS 201) fueled by natural gas) at a rate of about 30 to 50 meters per minute. The ends or sides of the modules are also exposed to a gas flame (or a corona in a combination gas/electric discharge flame) to activate the edges for application of a second hot-melt adhesive (edge adhesive).

Module edges can be exposed to the flame at a rate of about 5 to 10 meters/minute.

5            In step 1205, the modules are loaded into position with, for example, a suction alignment system that loads the modules from a cassette into position onto a processing table or conveyor.

10           In step 1210, the modules are fed into a laminating machine, and a first adhesive is applied to a substrate surface of the module. The adhesive can be metered or periodically applied to the bottom surface of the modules if the modules are spaced apart from each other.

15           In step 1215, the flexible membrane is adhered to the modules. The membrane can be placed in tension using a roller system for better mating of the membrane and the hot-melt coated modules.

20           In step 1220, the module and the membrane are pressed together with a smoothing unit (calendar rollers) to mate or adhere the module and membrane together. The lamination pressure is set either by gap or pressure up to, for example, about 300 N/cm for a total of 10,000N over the length of the calendar rollers.

25           In step 1225, the laminated product is permitted to set and cool.

30           In step 1230, a second adhesive, e.g., a HENKEL MM6240 adhesive, is applied to the elongated, leading, and trailing edges of the panel as a protective seal or pottant to protect the edges against weathering, moisture and other environmental pollutants that could damage the modules or cause the modules to be separated from the flexible membrane. Exemplary edge seals or pottants that can be utilized include ethylmethacrylate, poly-n-butyl-acrylate, EVA and elastomeric pottants EPDM and polyurethane.

5 In step 1235, as necessary, additional seals and protective layers can be applied to the panel. For example, a top protective layer can also be applied to the modules for further protection. The cover layer provides further protection against environmental elements while being transparent or mostly transparent to sunlight (e.g., 90% transmission). Example outer layer materials that can be used include, but are not limited to, Tedlar, a polyvinylfluoride (PVF), Kynar, a poly-vinylidene fluoride, flexible plexiglass DR-61K and V811 from Rohn & Hass.

15 In step 1240, the panels are then electrically wired and cut to length. Series wiring of a panel is accomplished using flat copper tape which is soldered between adjacent modules. Soldering points are accessed by cutting circular holes through the bottom layer or roof side of the flexible membrane at the location of the module solder pads. A power lead for each panel includes two "quick-connect" plugs which are soldered to the positive and negative terminal leads of the series wired modules. The power leads are connected to other panels, to a combiner box, to DC electrical devices or directly to a power inverter.

25 In step 1245, after the electrical lead soldering is completed, the copper tape and power leads are encapsulated in PVC by hot-air welding, RF welding or hot-melt adhering an adequate strip of compatible flexible membrane to the central underside of the larger flexible membrane thereby fully encapsulating and hermetically sealing and insulating the electrical solder connections of the panel.

30 Referring now to Figures 13 - 18, embodiments of an integrated photovoltaic roofing system constructed according to the invention will be discussed. The system S of Figure 13 includes several photovoltaic modules (e.g., modules 1310A-D)

that are attached to a flexible membrane 1312. On each of the photovoltaic modules 1310A-D, a pair of leads (e.g., wires 1314A-D) extends from a junction box 1316A-D. Each of the wire pairs 1314A-D are routed to a conduit (e.g., a tray or trunking) 1318 positioned in relatively close proximity to the wire pairs 1314A-D. Connections between the photovoltaic modules 1310A-D and to other components such as an inverter 1320 may be made by connecting leads (e.g., wires; not shown) inside the conduit 1318.

This embodiment provides a relatively simple manner of connecting conventional photovoltaic modules that have connection wires extending from the photovoltaic modules. Moreover, as all connections may be made within the conduit 1318, the connections are protected from the environment. In addition, provisions may be made in the conduit 1318 to provide strain relief for the wire pairs 1314A-D.

In some embodiments, the conduit 1318 may include one or more support members 1322 to raise the conduit 1318 above the photovoltaic modules 1310A-D. This facilitates ease of connectivity between the photovoltaic modules 1310A-D because the wire pairs 1314A-D from the photovoltaic modules 1310A-D may be easily routed through holes (not shown) in the bottom of the conduit 1318. Similarly, leads (e.g., wires) 1324 from the inverter 1320 to the conduit 1318 may be routed through a hole (not shown) on the bottom of the conduit 1318.

As will be discussed in more detail below, the embodiment of Figure 13 may include different numbers of photovoltaic modules 1310A-D having different numbers of solar cells 1326. In addition, the photovoltaic modules 1310A-D and the conduit 1318 may be arranged in various configurations.

Examples of the connections made in the conduit 1318 will be discussed in more detail in conjunction with Figure 14.



Figure 14 is a top view of a portion of the system of Figure 13. The tops of two junction boxes 1410A-B and a conduit 1412 are not shown to illustrate their internal wiring connections.

A photovoltaic module 1416A includes two electrical connectors (e.g., soldering pads or wires or copper tape leads) 1418A and 1418B that constitute the physical electrical connectors for the positive and negative connections to photovoltaic module, respectively. A photovoltaic module 1416B includes two similar electrical connectors 1418C-D. These electrical connectors provide connectivity to the solar cells in each module in a similar manner as, for example, the leads and connectors 170, 171, 170a and 170b discussed above. In contrast with the previously discussed leads and connectors, however, the electrical connectors 1418A-D may be located on the top surface of the photovoltaic modules 1416A-B.

A pair of electrical wires (e.g., wire pairs 1420A-B and 1420C-D) is attached to each of the electrical connectors (e.g., electrical connectors 1418A-B and 1418C-D, respectively) using solder connections 1421A-D. The wire pairs 1420A-D are routed through one or more holes 1422 in the bottom side of the conduit 1412.

When the system is installed on a roof, an installer connects electrical wires 1424A-C in the conduit 1412 to the wires 1420A-D from each photovoltaic module 1416A-B. In the example of Figure 14, the photovoltaic modules 1416A-B are connected in series. It should be appreciated, however, that parallel or other types of connections may be used to connect the photovoltaic modules 1416A-B together and/or to other components such as an inverter (not shown).

Typically, connectors 1426A-D are attached to the free ends of the wires 1420A-D. For example, the connectors may be

"quick-connect" connectors such as Model Nos. PV-KST3I UR (multi-contact male connector) or PV-KBT3I UR (multi-contact female connector) sold by Multi-Contact USA, Santa Rosa, CA.

When connectors 1426A-D are attached to the wires 1420A-D from the photovoltaic modules 1416A-B, compatible connectors 1428A-D are attached to the electrical wires 1424A-C in the conduit 1412. In this case, the system may be installed in the field relatively quickly by simply connecting each of the connectors 1426A-D and 1428A-D together.

Figure 15 illustrates an exploded view of one embodiment of a conduit 1510 constructed of PVC coated sheet metal. The main portion of the conduit 1510 consists of a square "U" shaped channel 1512. A top piece 1514 fits over the channel 1512 to keep rain and other material out of the conduit 1510. In addition, an end cap 1516 may be attached to each end of the channel 1512. The end caps 1516 and/or the top piece 1514 may be attached to the channel 1512 using a variety of attachment materials including, without limitation, rivets, screws and adhesives.

Depending on the layout and the number of the photovoltaic modules in the system, the conduit 1510 may consist of several conduit segments (not shown). In addition, the shape of the entire conduit structure may take many forms other than the straight conduit depicted in Figure 13. For example, the conduit structure may be in the shape of an "L," a "T" or any other shape required to effectively connect photovoltaic modules together. In these instances the conduit structure may include coupling members including, without limitation, TEEs and elbows (not shown).

In some embodiments, grommets 1518 are placed in the holes 1520 in the conduit 1510. The grommets 1518 may prevent excess moisture from entering the conduit 1510. Typically,

the grommets 1518 are relatively flexible and are sized so that their inside diameter is slightly smaller the outside diameter of the connectors 1426A-D (See Figure 14). In this way, the grommets 1518 may provide strain relief for the wires 1420A-D since the grommets 1518 may prevent the wires 1420A-D from being readily pulled out of the conduit 1510. The grommets 1518 typically are constructed of rubber or some other type of slightly flexible material.

In some embodiments one or more support members 1522 are attached to the bottom of the conduit 1510 to raise the conduit 1510 above the surface of the roof (not shown) or the flexible membrane 1312 (See Figure 13). The support member 1522 may be constructed of a variety of materials including, without limitation, wood, sheet metal and PVC. A base material 1524 may be attached to the bottom of the support member 1522 to, for example, prevent damage to the flexible membrane 1312, the roof and the support member 1522. The base material 1524 may be constructed of, without limitation, a self-adhesive PVC membrane. The support member 1522 may be attached to the conduit 1510 using various attachment materials including, without limitation, screws and adhesives.

The conduit 1510 may be securely placed on the roof or flexible membrane 1312 in many ways. In some embodiments, the mass of the conduit 1510 is sufficient to hold the conduit 1510 in place on the roof or the flexible membrane 1312 without physically attaching the conduit 1510 to the roof or the flexible membrane 1312. In some embodiments, ballast may be added to the conduit 1510. In other embodiments the conduit 1510 may be physically attached to the roof or flexible membrane using conventional roofing attachment techniques.

From the above, it should be appreciated that a conduit as described herein may be constructed in a variety of ways. For example, a conduit may be made in different shapes, sizes and configurations. In addition, a conduit may be constructed of a variety of materials including, without limitation, sheet metal, aluminum, and PVC materials.

Figure 16 illustrates a side cut-out view of a portion of one embodiment of an integrated photovoltaic module and flexible membrane that may be used in the embodiments of Figures 13 - 18. In a manner similar to that discussed above in conjunction with Figures 1 - 12, the integrated component (e.g., a panel) 1610 of Figure 16 is constructed by attaching one or more photovoltaic modules 1612 to one or more flexible membranes 1614.

One example of flexible membrane sheet 1614 that can be used is a single-ply membrane, e.g., an EnergySmart® S327 Roof Membrane, available from Sarnafil, Inc., Roofing and Waterproofing Systems, 100 Dan Road, Canton, Massachusetts. It should be appreciated however, that many other flexible membranes and single-ply membranes can be utilized as discussed above in conjunction with the embodiments of Figures 1 - 12.

The photovoltaic module 1612 is similar to the photovoltaic modules discussed above in conjunction with Figures 4 - 6. The primary difference is that the electrical connectors for the photovoltaic module 1612 shown in Figure 16 may be located on the top of the photovoltaic module 1612. An example of a photovoltaic module of this type is a PVL-128 UNI-SOLAR® solar module (e.g., Model No. 22L-T), available from Bekaert ECD Solar Systems, LLC, 3800 Lapeer Road, Auburn Hills, Michigan.

As discussed above in conjunction with Figure 5, the photovoltaic module is constructed of several layers. Briefly, this particular photovoltaic module 1610 may include a top Tefzel layer 1622, a first ethylene-propylene rubber (EVA) layer 1624, a fiberglass layer 1626, a photoreactive or solar cell layer 1628, a second EVA layer 1630, and a Tedlar layer 1632.

Figure 16 also shows a negative internal electrode 1634 and a positive internal electrode 1636 mounted within the second EVA layer 1630 of the module 1610 in a similar manner as discussed above for internal electrodes 170a and 170b. The negative internal electrode 1634 is insulated from the photoreactive layer 1628 by an insulation strip or layer 1638 to prevent a short circuit. The internal electrodes 1634 and 1636 connect to electrical connectors 1642A-B (e.g., electrical connectors 1418A-B in Figure 14) via connections 1644A-B, respectively. The connections 1644A-B may be insulated, as necessary, from one or more of the layers (e.g., layers 1622, 1624, 1626 and/or 1628) of the module.

The photovoltaic module 1612 may be attached to the flexible membrane 1614 using materials and techniques as discussed above in conjunction with Figures 1 - 12. For example, a bottom surface 1620 of the photovoltaic module 1612 may be adhered to a top surface 1616 of the flexible membrane 1614 with an adhesive 1618. One exemplary adhesive 1618 that can be used to bond or laminate the bottom surface 1620 of the photovoltaic module 1612 to the top surface 1616 of the flexible membrane 1614 is a reactive polyurethane hot-melt QR4663, available from Henkel KGaA, Kenkelstrasse 67, 40191 Duesseldorf, Germany. It should be appreciated, however, that other adhesives and other adhesion techniques may be used to attach a photovoltaic module 1612 to a flexible membrane 1614.

In a manner similar to that discussed above in conjunction with Figures 1 - 12, an edge sealant 1640 may be applied to the edges of photovoltaic module 1610. More specifically, an edge sealant 1640 can be applied to seal or cover any gaps or an edge between an adhesive layer 1618 and the bottom surface 1620 of photovoltaic module 1610, as well as an edge between the adhesive layer 1618 and the top surface 1616 of the flexible membrane 1614.

The photovoltaic module of Figure 16 includes a weatherproof junction box (not shown) that protects the solder connection on the electrical connectors 1642A-B (e.g., electrical connectors 1418A-D in Figure 14). Referring to Figure 17, an injection molded plastic junction box 1710 is placed over the electrical connectors (not shown) and includes a cable port 1712 through which wires 1714 soldered to the electrical connectors may be routed to holes 1716 in a conduit 1718. The junction box 1710 is weatherproofed by injecting a potting material 1720, e.g., a silicone sealant, into an injection port 1722 of the junction box 1710, then inserting a plug 1724 into the injection port 1722.

Figures 18A and 18B represent one example of a method of constructing and installing a system as described in Figure 13 - 17. This process is similar to the process described above in conjunction with Figure 12. For example, steps 1800, 1805, 1810, 1815, 1820, 1825 and 1830 may be identical to steps 1200, 1205, 1210, 1215, 1220, 1225 and 1230 described in conjunction with Figure 12. Step 1835 is similar to step 1235 with the exception that provisions may be made to avoid laminating over the top of the electrical connectors on the top surface of the modules.

In step 1840, the integrated component (e.g., panel) 1610 is cut to length and cut to various dimensions as needed.

5      In step 1845, wires 1714 and the junction box 1710 are attached to the top of the integrated panel 1610. In some embodiments, the wires 1714 consists of a PV cable that is approximately three feet long. The wires 1714 are soldered to the electrical connectors (e.g., the "+" and "-" electrical connectors). The junction box 1710 is then placed over the electrical connectors so that the wires 1714 extend through a cable port 1712 in the junction box 1710. The bottom of the junction box 1710 includes a Butyl tape pressure sensitive adhesive 1728 that fastens the junction box 1710 to the top surface of the integrated panel 1610. A potting material 1720 (e.g., silicone or a suitable caulking) is then injected into the injection port 1722 on the top of the junction box 1710 to protect the solder connections from the elements and provide some measure of strain relief. Next, an injection port plug 1724 is glued into the injection port 1722. If applicable, connectors 1726 are attached to the free ends of the wires 1714.

20      In a similar manner as discussed above in conjunction with Figures 1 - 12, the integrated panel 1610 can be rolled up for storage and transportation. The integrated panel may then be shipped to the building site, unrolled, and applied to a rooftop.

25      Referring now to Figure 18B, one example of a field installation procedure will be discussed. In step 1850, the integrated panels are unrolled on a roof and attached to the roof as discussed above. In step 1855, the conduit is positioned as necessary to enable the wires and connectors from the integrated panels to be routed into the conduit. For example, the conduit may be located at adjacent ends of the modules to which the electrical wires are attached. In step 1860, the integrated panels are connected together with

appropriate wiring in the conduit. In addition, the wiring may be connected to another component such as an inverter. In some embodiments the connection to the inverter may be made via screw lugs in the inverter. Finally, in step 1865 assembly of the conduit is completed by, for example, placing the top pieces on the conduit.

Most of the components in a system as described in Figures 13 - 18 may be constructed and configured in a manner similar to the construction and configurations described above in conjunction with Figures 1 - 12.

For example, a conduit may be placed adjacent to or between integrated photovoltaic roofing components and modules similar to those depicted in Figures 1, 2 and 9. Typically, the modules are positioned so that the ends of the modules to which the electrical wires connect are placed adjacent one another. The conduit may then be located at these adjacent ends of the modules. The conduit may be placed in areas that corresponding to the common or central areas 160 and/or ends 134. Here, the connections in these areas as depicted in Figures 1, 2 and 9 would be made in the conduit rather than in the corresponding component or panel.

Similarly, in Figure 3, a conduit may be located between the two sets of modules 110 - 115 and 116 and 121. Again, connections between modules may be made in the conduit rather than within the panel.

Having described various embodiments of the present invention, persons of ordinary skill in the art recognize that the integrated photovoltaic component, panel and system of the present invention overcomes the shortcomings of conventional roofing materials, add-on solar modules, and known panels that also include solar modules to provide a more effective roofing solution. The present invention reduces the amount of wiring



and related hardware that is typically needed to connect solar  
modules and connect solar modules to an inverter. The present  
5 invention also simplifies wiring since fewer connections are  
made, and the fewer connections are made within a central  
area.

The foregoing description of embodiments of the present  
invention have been presented for the purposes of illustration  
10 and description. It is not intended to be exhaustive or to  
limit the invention to the precise forms disclosed. Many  
modifications and variations are possible in light of the  
above teaching. For example, the integrated photovoltaic  
roofing panel can be used with many different modules,  
15 flexible membranes, adhesives, and arrays of module  
configurations. Additionally, the integrated photovoltaic  
component and panel can be used not only as a roofing  
component, but can also be applied to walls, canopies, tent  
structures, and other building structures. Further, the  
20 integrated photovoltaic roofing panel can be utilized with  
many different building structures, including residential,  
commercial and industrial building structures. It is intended  
that the scope of the invention be limited not by this  
detailed description, but rather by the claims appended  
25 hereto.

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